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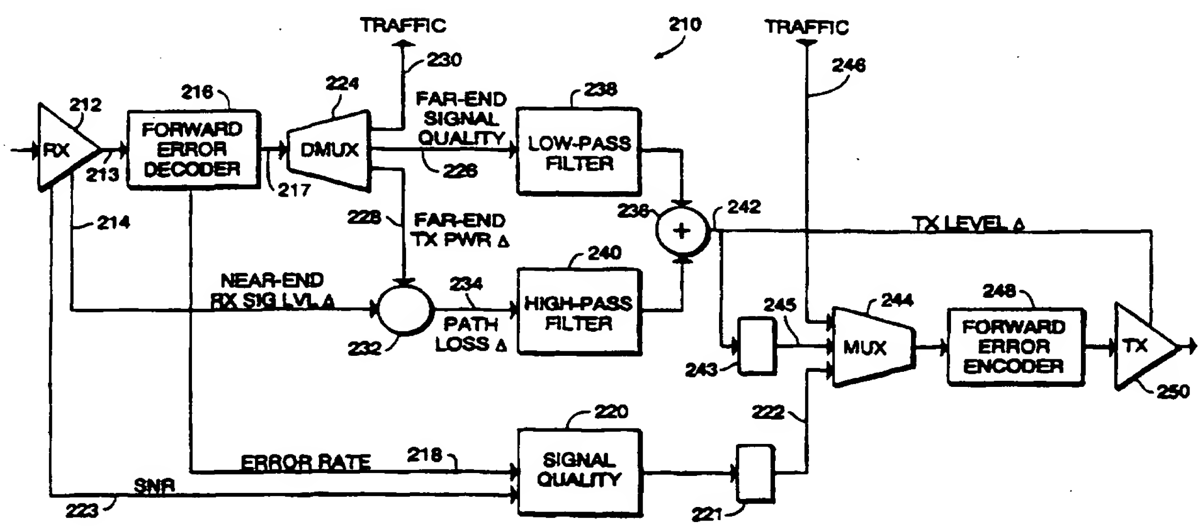

(57) Abstract

Two-way adaptive power control and signal quality monitoring and power control responsive thereto are provided for controlling the power output levels of transmitters (210) to the minimum necessary for satisfactory communications. Each transmission includes a code representative of the transmitter output power level. Receivers (212) compare this code to the received signal strength and ajust their associated transmitter power output level accordingly. Bit error rate (218) and SNR (223) are monitored by receivers to develop a measure of signal quality (220). A signal quality code is transmitted (250) to remote units and transmission output power level is adjusted in response.

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CELLULAR COMMUNICATIONS POWER CONTROL SYSTEM

BACKGROUND

The invention relates to communication systems and in particular, to a cellular mobile communications system having integrated satellite and ground nodes.

The cellular communications industry has grown at a fast pace in the United States and even faster in some other countries. It has become an important service of substantial utility and because of the growth rate, saturation of the existing service is of concern. High density regions having high use rates, such as Los Angeles, New York and Chicago are of most immediate concern. Contributing to this concern is the congestion of the electromagnetic frequency spectrum which is becoming increasingly severe as the communication needs of society expand. This congestion is caused not only by cellular communications systems but also by other communications systems. However, in the cellular communications industry alone, it is estimated that the number of mobile subscribers will increase on a world-wide level by an order of magnitude within the next ten years. The radio frequency spectrum is limited and in view of this increasing demand for its use, means to more efficiently use it are continually being explored.

Existing cellular radio is primarily aimed at providing mobile telephone service to automotive users in developed metropolitan areas. For remote area users, airborne users, and marine users, AIRFONE and INMARSAT services exist but coverage is incomplete and service is relatively expensive. Mobile radio satellite systems in an advanced planning stage will probably provide improved direct-broadcast voice channels to mobile subscribers in remote areas but still at significantly higher cost in comparison to existing ground cellular service. The ground cellular and planned satellite technologies complement one another in geographical coverage in that the ground cellular communications service provides voice telephone service in relatively developed urban and suburban areas but not in sparsely populated areas, while the planned earth orbiting satellites will serve the sparsely populated areas.

Cellular communications systems divide the service areas into geographical cells, each served by a base station or node typically located at its center. The central node transmits sufficient power to cover its cell area with adequate field strength. If a mobile user moves to a new cell, the radio link is switched to the new node provided there is an available channel. Present land mobile communication systems typically use a frequency modulation (FM) approach and because of the limited interference rejection capabilities of FM modulation, each radio channel may be used only once over a wide geographical area encompassing many cells. This means that each cell can use only a small fraction of the total allocated radio frequency band, resulting in an inefficient use of the available spectrum. In some cases, the quality of

speech is poor because of the phenomena affecting FM transmission known as fading and "dead spots." The subjective effect of fading is repeated submersion of the voice signal in background noise frequently many times per second if the mobile unit is in motion. The problem is exacerbated by interference from co-channel users in distant cells and resultant crosstalk due to the limited interference rejection capability of FM. Additionally, communications privacy is relatively poor; the FM signal may be heard by others who are receiving that frequency.

In the case where one band of frequencies is preferable over others and that one band alone is to be used for mobile communications, efficient communications systems are necessary to assure that the number of users desiring to use the band can be accommodated. For example, there is presently widespread agreement on the choice of L-band as the technically preferred frequency band for the satellite-to-mobile link in mobile communications systems. In the case where this single band is chosen to contain all mobile communications users, improvements in spectral utilization in the area of interference protection and in the ability to function without imposing intolerable interference on other services will be of paramount importance in the considerations of optimal use of the scarce spectrum.

Troubling both terrestrial and satellite communication is channel fading, in which communications channel experiences fading due to numerous factors such as changes in weather conditions, signal propagation, local terrain etc..

Satellite transceivers are generally located in geosynchronous earth orbit, approximately 22,300 miles from earth, and as such, are approximately the same distance from mobile units. Accordingly, path loss in the satellite channel is relatively minor, on the order of only a few dB. Unfortunately, satellite transmissions still experience substantial fading due to the direct component of the satellite signal being summed with multiply reflected components of the satellite signal, thereby inducing channel fading of several dB.

In contrast to satellite transmission, the terrestrial to mobile transmission is substantially effected by the distance between the mobile unit and the cell site. For example, one mobile unit may be located at a distance many miles from the cell site, while another may be only yards away. Accordingly, path loss variations of terrestrial transmissions may be orders of magnitude greater than experienced by satellite transmissions. Further, the terrestrial transmissions typically experience substantial fading due to the signal being reflected from many different features of the physical environment. As a result, a signal may arrive at a mobile unit from many different directions causing both constructive and destructive summation of the signals. Additionally, the transmitted signal may be partially obstructed by buildings, foliage, and the like to produce additional signal fading.

In order to overcome these constraints, the transceivers of typical communications systems commonly radiates at a power level which is 30 to 40

dB greater than is required on the average in order to overcome fading nulls. This results in greatly increased inter-system interference, reduced battery life and a reduction of potential users in the communications system.

The severely limited commodity in the satellite links is satellite prime power, a major component of the weight of a communication satellite and thereby a major factor in satellite cost. Generally in systems such as this, the down links to individual users are the largest power consumers and thus for a limited satellite source power, may provide the limiting factor on the number of users that can be served. Thus it is important to design the system for minimum required power per user.

It would be desirable to provide a power control system to compensate for fading and interference without exceeding the minimum amount of power necessary to overcome such interference. To this end, numerous designs have been developed in an attempt to control transmitter power. A transmitter power control system is disclosed in the patent to Wheatley, III, U.S. Patent No. 5,267,262. Wheatley, III discloses the cell site measuring the signal strength and signal quality, i.e. bit error rate, of a signal transmitted by the mobile unit. The cell site processes the signal strength and signal quality to determine the desired signal strength for that mobile unit and transmits a power adjustment command back to the mobile unit. This power adjustment command is combined with the mobile unit's one way estimate of received signal strength to obtain a final value of the mobile unit transmitter power.

Unfortunately, Wheatley discloses telemetering the transmit power only as a static parameter at call setup time, not for the purpose, nor at a sample rate sufficient to support dynamic compensation of the received signal strength for adaptive power variations in a two-way adaptive power control system where both transmitters continuously adapt their respective transmit power.

A similar concept to control transmitter power is disclosed in Wilson, et al., U.S. Patent No. 5,293,639. Wilson et al. discloses the control of the output power level of a transmitted signal by the mobile unit transmitting a first message on a first communications channel to a repeater station. The repeater station measures the quality of the received first message to produce a quality metric representative of the quality of the first message. The repeater station retransmits the first message back to the mobile unit, appending the quality metric for determination by the mobile unit of its output power. Unfortunately, the retransmission of the first message is unnecessary in many system applications thus requiring additional power, and causing unnecessary signal interference.

It is therefore an object of the present invention to provide an improved method and apparatus for controlling the transmitter power of a transceiver of a cellular communications system including an adaptive two-way power control system which continuously maintains each transmitted signal power at a minimum necessary level, adapting rapidly to, and accommodating signal fade dynamically and only as necessary.

SUMMARY OF THE INVENTION

Briefly and in general terms, the invention, is directed to a cellular communications system having an adaptive transmitter power control system and method compensate for received signal strength variations, such as those caused by buildings, foliage and other obstructions. Each receiver determines the quality of the received signal and provides a local quality signal to its associated transmitter in the respective transceiver indicative of that received signal quality. Each transmitter also transmits the local quality signal provided to it from its associated receiver and the transceiver is additionally responsive to the quality signal received from the other transceiver with which it is in communication to control its own output power in the response to that quality signal.

In yet a further aspect, a path loss measure is derived from the received signal strength and from data included in each transmitted signal which indicates that transmitter's output power level. Based on the derived path loss and the transmitter's power level data, the receiver can then adjust the power output of its own associated transmitter accordingly.

In a more detailed aspect, the error rate of the received signal is determined in providing the quality signal, and in another aspect, the signal-to-noise ratio (SNR) is measured to determine quality. The transceiver receiving

the error rate signal or the SNR from the other transceiver controls its own transmitter power output in response.

Other aspects and advantages of the invention will become apparent from the following detailed description and the accompanying drawings, illustrating by way of example the features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing an overview of the principal elements of a communications system in accordance with the principles of the invention;

FIG. 2 is a diagram of the frequency sub-bands of the frequency band allocation for a cellular system;

FIG. 3 is a overview block diagram of a communications system in accordance with the principles of the invention without a network control center;

FIG. 4 is a diagram showing the interrelationship of the cellular hierarchical structure of the ground and satellite nodes in a typical section and presents a cluster comprising more than one satellite cell;

FIG. 5 is a block diagram of a satellite link system showing the user unit and satellite node control center;

FIG. 6 is a block diagram of one embodiment of satellite signal processing in the system of FIG. 5;

FIG. 7 is a functional block diagram of a user transceiver showing an adaptive power control system;

FIGS. 8a through 8h show timing diagrams of an adaptive, two-way power control system; and

FIG 9 is a functional diagram of a two-way power control system incorporating telemetered signal-quality deficiency supervisory control.

FIG 10 is a functional diagram of a power control system combining adaptive signal quality power control and adaptive path loss power control.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As is shown in the exemplary drawings, the invention, though not limited to, is preferredly embodied in a cellular communications system utilizing integrated satellite and ground nodes both of which use the same modulation, coding, and both responding to an identical user unit.

Referring now to FIG. 1, an overview of a preferred communications system 10 is presented showing the functional inter-relationships of the major elements. The system network control center 12 directs the top level allocation of calls to satellite and ground regional resources throughout the system. It also is used to coordinate system-wide operations, to keep track of user locations, to perform optimum allocation of system resources to each call, dispatch facility command codes, and monitor and supervise overall system health. The regional node control centers 14, one of which is shown, are connected to the system network control center 12 and direct the allocation of calls to ground nodes within a major metropolitan region. The regional node control center 14 provides access to and from fixed land communication lines, such as commercial telephone systems known as the public switched telephone network (PSTN). The ground nodes 16 under direction of the respective regional node control center 14 receive calls over the fixed land line network encode them, spread them according to the unique spreading code assigned to each designated user, combine them into a composite signal, modulate that composite signal onto the transmission carrier, and broadcast them over the cellular region covered.

Satellite node control centers 18 are also connected to the system network control center 12 via status and control land lines and similarly handle calls designated for satellite links such as from PSTN, encode them, and multiplex them with other similarly directed calls into an uplink trunk, which is beamed up to the designated satellite 20. Satellite nodes 20 receive the

uplink trunks, frequency demultiplex the calls intended for different satellite cells, frequency translate and direct each to its appropriate cell transmitter and cell beam, and broadcast the composite of all such similarly directed calls down to the intended satellite cellular area. As used herein, "backhaul" means the link between a satellite 20 and a satellite node control center 18. In one embodiment, it is a K-band frequency while the link between the satellite 20 and the user unit 22 uses an L-band or an S-band frequency.

As used herein, a "node" is a communication site or a communication relay site capable of direct one- or two-way radio communication with users. Nodes may include moving or stationary surface sites or airborne or satellite sites.

User units 22 respond to signals of either satellite or ground node origin, receive the outbound composite signal, de-modulate, and decode the information and deliver the call to the user. Such user units 22 may be mobile or may be fixed in position. Gateways 24 provide direct trunks, that is, groups of channels, between satellite and the ground public switched telephone system or private trunk users. For example, a gateway may comprise a dedicated satellite terminal for use by a large company or other entity. In the embodiment of FIG. 1, the gateway 24 is also connected to that system network controller 12.

All of the above-discussed centers, nodes, units and gateways are full duplex transmit/receive performing the corresponding inbound (user to system) link functions as well in the inverse manner to the outbound (system to user) link functions just described.

Referring now to FIG. 2, the allocated frequency band 26 of a communications system is shown. The allocated frequency band 26 is divided into 2 main sub-bands, an outgoing sub-band 25 and an incoming sub-band 27. Additionally the main sub-bands are themselves divided into further sub-bands which are designated as follows:

OG: Outbound Ground 28 (ground node to user)

OS: Outbound Satellite 30 (satellite node to user)

OC: Outbound Calling and Command 32 (node to user)

IG: Inbound Ground 34 (user to ground node)

IS: Inbound Satellite 36 (user to satellite node)

IC: Inbound Calling and Tracking 38 (user to node)

All users in all cells use the entire designated sub-band for the described function. Unlike existing ground or satellite mobile systems, there is no necessity for frequency division by cells; all cells may use these same basic six sub-bands. This arrangement results in a higher frequency reuse factor as is discussed in more detail below.

In one embodiment of the communication system, a mobile user's unit 22 will send an occasional burst of an identification signal in the IC sub-band either in response to a poll or autonomously. This may occur when the unit 22 is in standby mode. This identification signal is tracked by the regional node control center 14 as long as the unit is within that respective region, otherwise the signal will be tracked by the satellite node or nodes. In another embodiment, this identification signal is tracked by all ground and satellite nodes capable of receiving it. This information is forwarded to the network control center 12 via status and command lines. By this means, the applicable regional node control center 14 and the system network control center 12 remain constantly aware of the cellular location and link options for each active user 22. An intra-regional call to or from a mobile user 22 will generally be handled solely by the respective regional node control center 14. Inter-regional calls are assigned to satellite or ground regional system resources by the system network control center 12 based on the location of the parties to the call, signal quality on the various link options, resource availability and best utilization of resources.

A user 22 in standby mode constantly monitors the common outbound calling frequency sub-band OC 32 for calling signals addressed to him by means of his unique spreading code. Such calls may be originated from either ground or satellite nodes. Recognition of his unique call code initiates the user unit 22 ring function. When the user goes "off-hook", e.g. by lifting the handset from its cradle, a return signal is broadcast from the user unit 22 to

any receiving node in the user calling frequency sub-band IC 38. This initiates a handshaking sequence between the calling node and the user unit which instructs the user unit whether to transition to either satellite, or ground frequency sub-bands, OS 30 and IS 36 or OG 28 and IG 34.

A mobile user wishing to place a call simply takes his unit 22 off hook and dials the number of the desired party, confirms the number and "sends" the call. Thereby an incoming call sequence is initiated in the IC sub-band 38. This call is generally heard by several ground and satellite nodes which forward call and signal quality reports to the appropriate system network control center 12 which in turn designates the call handling to a particular satellite node 20 or regional node control center 14. The call handling element then initiates a handshaking function with the calling unit over the OC 32 and IC 38 sub-bands, leading finally to transition to the appropriate satellite or ground sub-bands for communication.

Referring now to FIG. 3, a block diagram of a communications system 40 which does not include a system network control center is presented. In this system, the satellite node control centers 42 are connected directly into the land line network as are also the regional node control centers 44. Gateway systems 46 are also available as in the system of FIG. 1. and connect the satellite communications to the appropriate land line or other communications systems. The user unit 22 designates satellite node 48 communication or ground node 50 communication by sending a predetermined code.

Referring now to FIG. 4, a hierarchical cellular structure is shown. A pair of clusters 52 of ground cells 54 are shown. Additionally, a plurality of satellite cells 56 are shown. Although numerals 54 and 56 point only to two cells each, this has been done to retain clarity in the drawing. Numeral 54 is meant to indicate all ground cells in the figure and similarly numeral 56 is meant to indicate all satellite cells. The cells are shown as hexagonal in shape, however, this is exemplary only. The ground cells may be from 3 to 15 km across although other sizes are possible depending on user density in the cell. The satellite cells may be approximately 200-500 km across as an example depending on the number of beams used to cover a given area. As shown, some satellite cells may include no ground cells. Such cells may cover undeveloped areas for which ground nodes are not practical. Part of a satellite cluster 58 is also shown. The cell members of such a cluster share a common satellite node control center 60.

Referring again to FIG. 1 as well as to FIG. 4, the satellite nodes 20 make use of large, multiple-feed antennas 62 which in one embodiment provide separate, relatively narrow beamwidth beams and associated separate transmitters for each satellite cell 56. For example, the multiple feed antenna 62 may cover an area such as the United States with, typically, about 100 satellite beams/cells and in one embodiment, with about 200 beams/cells. As used herein, "relatively narrow beamwidth" refers to a beamwidth that results in a cell of 500 km or less across. The combined satellite/ground nodes system provides a hierarchical geographical cellular structure. Thus within a

dense metropolitan area, each satellite cell 56 may further contain as many as 100 or more ground cells 54, which ground cells would normally carry the bulk of the traffic originated therein. The number of users of the ground nodes 16 is anticipated to exceed the number of users of the satellite nodes 20 where ground cells exist within satellite cells. Because all of these ground node users would otherwise interfere as background noise with the intended user-satellite links, in one embodiment the frequency band allocation may be separated into separate segments for the ground element and the space element as has been discussed in connection with FIG 2. This combined, hybrid service can be provided in a manner that is smoothly transparent to the user. Calls will be allocated among all available ground and satellite resources in the most efficient manner by the system network control center 12.

An important parameter in most considerations of cellular radio communications systems is the "cluster", defined as the minimal set of cells such that mutual interference between cells reusing a given frequency sub-band is tolerable provided that such "co-channel cells" are in different clusters. Conversely all cells within a cluster must use different frequency sub-bands. The number of cells in such a cluster is called the "cluster size". It will be seen that the "frequency reuse factor", i.e. the number of possible reuses of a frequency sub-band within the system is thus equal to the number of cells in the system divided by the cluster size. The total number of channels that can be supported per cell, and therefore overall bandwidth efficiency of the system is thus inversely proportional to the cluster size.

Referring now to FIG. 5, a block diagram is shown of a typical user unit 22 to satellite 20 to satellite node control 18 communication and the processing involved in the user unit 22 and the satellite node control 18. In placing a call for example, the handset 64 is lifted and the telephone number entered by the user. After confirming a display of the number dialed, the user pushes a "send" button, thus initiating a call request signal. This signal is processed through the transmitter processing circuitry 66 which includes spreading the signal using a calling spread code. The signal is radiated by the omni-directional antenna 68 and received by the satellite 20 through its narrow beamwidth antenna 62. The satellite processes the received signal as will be described below and sends the backhaul to the satellite node control center 18 by way of its backhaul antenna 70. On receive, the antenna 68 of the user unit 22 receives the signal and the receiver processor 72 processes the signal. Processing by the user unit 22 will be described in more detail below in reference to FIG. 7.

The satellite node control center 18 receives the signal at its antenna 71, applies it to a circulator 73, amplifies 74, frequency demultiplexes 76 the signal separating off the composite signal which includes the signal from the user shown in FIG. 5, splits it 78 off to one of a bank of code correlators, each of which comprises a mixer 80 for removing the spreading and identification codes, an AGC amplifier 82, the FECC demodulator 84, a demultiplexer 86 and finally a voice encoder/decoder (CODEC) 88 for converting digital voice information into an analog voice signal. The voice

signal is then routed to the appropriate land line, such as a commercial telephone system. Transmission by the satellite node control center 18 is essentially the reverse of the above described reception operation.

Referring now to FIG. 6, the satellite transponder 90 of FIG. 5 is shown in block diagram form. A circulator/diplexer 92 receives the uplink signal and applies it to an L-band or S-band amplifier 94 as appropriate. The signals from all the M satellite cells within a "cluster" are frequency multiplexed 96 into a single composite K-band backhaul signal occupying M times the bandwidth of an individual L-/S-band mobile link channel. The composite signal is then split 98 into N parts, separately amplified 100, and beamed through a second circulator 102 to N separate satellite ground cells. This general configuration supports a number of particular configurations various of which may be best adapted to one or another situation depending on system optimization which for example may include considerations related to regional land line long distance rate structure, frequency allocation and subscriber population. Thus, for a low density rural area, one may utilize an M-to-1 ($M > 1$, $N = 1$) cluster configuration of M contiguous cells served by a single common satellite ground node with M limited by available bandwidth. In order to provide high-value, long distance service between metropolitan areas, already or best covered for local calling by ground cellular technology, an M-to-M configuration would provide an "inter-metropolitan bus" which would tie together all occupants of such M satellite cells as if in a single local calling region. To illustrate, the same cells (for example, Seattle, Los

Angeles, Omaha and others) comprising the cluster of M user cells on the left side of FIG. 6, are each served by corresponding backhaul beams on the right side of FIG. 6.

Referring now to FIG. 7, a functional block diagram of a typical user unit 22 is shown. The user unit 22 comprises a small, light-weight, low-cost, mobile transceiver handset with a small, non-directional antenna 68. The single antenna 68 provides both transmit and receive functions by the use of a circulator/diplexer 104 or other means. It is fully portable and whether stationary or in motion, permits access to a wide range of communication services from one telephone with one call number. It is anticipated that user units will transmit and receive on frequencies in the 1-3 GHz band but can operate in other bands as well.

The user unit 22 shown in FIG. 7 comprises a transmitter section 106 and a receiver section 108. For the transmission of voice communication, a microphone couples the voice signal to a voice encoder 110 which performs analog to digital encoding using one of the various modern speech coding technologies well known to those skilled in the art. The digital voice signal is combined with local status data, and/or other data, facsimile, or video data forming a composite bit stream in digital multiplexer 112. The resulting digital bit stream proceeds sequentially through forward error encoder 114, symbol or bit interleaver 116, symbol or bit, phase, and/or amplitude modulator 118, narrow band IF amplifier 120, wideband multiplier or spreader

122, wide band IF amplifier 124, wide band mixer 126, and final power amplifier 128. Oscillators or equivalent synthesizers derive the bit or baud frequency 130, pseudo-random noise or "chip" frequency 132, and carrier frequency 134. The PRN generator 136 comprises deterministic logic generating a pseudo-random digital bit stream capable of being replicated at the remote receiver. The ring generator 138 on command generates a short pseudo-random sequence functionally equivalent to a "ring.".

The transceiver receive function 108 demodulation operations mirror the corresponding transmit modulation functions in the transmitter section 106. The signal is received by the non-directional antenna 68 and conducted to the circulator 104. An amplifier 142 amplifies the received signal for mixing to an IF at mixer 144. The IF signal is amplified 146 and multiplied or despread 148 and then IF amplified 150 again. The IF signal then is conducted to a bit or symbol detector 152 which decides the polarity or value of each channel bit or symbol, a bit or symbol de-interleaver 154 and then to a forward error decoder 156. the composite bit stream from the FEC decoder 156 is then split into its several voice, data, and command components in the de-multiplexer 158. Finally a voice decoder 160 performs digital to analog converting and results in a voice signal for communication to the user by a speaker or other means. Local oscillator 162 provides the first mixer 144 LO and the bit or symbol detector 152 timing. A PRN oscillator 164 and PRN generator 166 provide the deterministic logic of the spread signal for despreading purposes.

The baud or bit clock oscillator 168 drives the bit in the bit detector 152, forward error decoder 156 and the voice decoder 160.

The bit or symbol interleaver 116 and de-interleaver 154 provide a type of coded time diversity reception which provides an effective power gain against multipath fading to be expected for mobile users. Its function is to spread or diffuse the effect of short bursts of channel bit or symbol errors so that they can more readily be corrected by the error correction code.

As an alternative mode of operation, provision is made for direct data or facsimile or other digital data input 170 to the transmitter chain and output 172 from the receiver chain.

A command decoder 174 and command logic element 176 are coupled to the forward error decoder 156 for receiving commands or information. By means of special coding techniques known to those skilled in the art, the non-voice signal output at the forward error decoder 156 may be ignored by the voice decoder 160 but used by the command decoder 174. An example of the special coding techniques are illustrated in FIG. 7 by the MUX 112 and DEMUX 158.

As shown, acquisition, control and tracking circuitry 178 are provided in the receiver section 108 for the three receive side functional oscillators 162,

164, 168 to acquire and track the phase of their counterpart oscillators in the received signal. Means for so doing are well known to those skilled in the art.

The automatic gain control (AGC) voltage 184 derived from the received signal is used in the conventional way to control the gain of the preceding amplifiers to an optimum value and in addition as an indicator of short term variations of path loss suffered by the received signal. By means to be described more in detail below, this information is combined with simultaneously received digital data 186 in a power level controller 188 indicating the level at which the received signal was originally transmitted to command the local instantaneous transmit power level to a value such that the received value at the satellite node control is approximately constant, independent of fading and shadowing effects. The level commanded to the output power amplifier 128 is also provided 190 to the transmitter multiplexer 112 for transmission to the corresponding unit.

In mobile and other radio applications, fading, shadowing, and interference phenomena result in occasional, potentially significant steep increases of path loss and if severe enough, may result in data loss. In order to insure that the probability that such a fade will be disruptive is acceptably low, conventional design practice is to provide a substantial excess power margin by transmitting at a power level that is normally as much as 10 to 40 dB above the average requirement. But this causes correspondingly increased battery usage, inter-system, and intra-system interference. In a CDMA

application, this can drastically reduce the useful circuit capacity of the channel.

In accordance with the principles of the invention is an adaptive two-way power control system which continually maintains each transmitted signal power at a minimum necessary level, adapting rapidly to and accommodating such fades dynamically, and only as necessary. In controlling the transmitted signal power, the adaptive power control system at each end, near-end and far-end, includes a unique hybrid combination of two complementary sensors, the first being a near-end signal strength measure and the second being a far-end signal quality measure, both in operation simultaneously and symmetrically, with respect to each end of the subject two-way communication link.

The signal strength measure is inferred from the near-end measure of received signal strength. In the subject invention, both ends of the link are under adaptive power control depending at least in part on local received signal strength measurement. Thus, the local received strength depends not only on the path loss but also on the instantaneous adapted power level at which the received signal was transmitted from the far end. In order to implement two-way adaptive control, the far-end transmitter continuously telemeters the adapted power at which it is transmitting, multiplexed by any of several available means signal information. Combining the locally measured received signal strength with far end telemetered transmit power level, the transceiver is able to determine the path loss or changes in the path loss of the received

signal. Assuming path reciprocity, this provides a first estimate of the path loss of the outgoing path, and in turn, a first estimate of the power or change in power needed by the local transmitter. This determination is fast, in that it responds almost instantaneously to path loss.

Further, the adaptive power control system in accordance with the invention comprises two main adaptive systems, the first being an adaptive signal quality power control system and the second being an adaptive path loss power control system. Each of these systems may be operated independently, but in a preferred embodiment are a combination of the adaptive signal quality power control system and the adaptive path loss power control system.

The adaptive power control system in accordance with the invention considers not only path loss but also a measure of data loss or "signal quality" reported to it from another unit with which it is in communication. Discussing now an embodiment of the adaptive signal quality system, as used herein, "signal quality" refers to the accuracy or fidelity of a received signal in representing the quantity or waveform it is supposed to represent. In a digital data system, this may be measured or expressed in terms of a bit error rate, or, if variable, the likelihood of exceeding a specified maximum bit error rate threshold. Signal quality involves more than just signal strength, depending also on noise and interference level, and on the variability of signal loss over time. Additionally, "grade of service" as used herein is a collective term including the concepts of fidelity, accuracy, fraction of time that

communications are satisfactory, etc., any of which may be used to describe the quality objectives or specifications for a communication service. Examples of grade of service objectives would include:

- bit error rate less than one in 10^3;

- ninety percent or better score on the voice diagnostic rhyme test;

and

- less than one-half percent probability of fade below threshold, although the exact numbers may vary depending on the application. This signal quality measurement, by comparison to a nominal signal quality or grade-of-service objective, provides a second estimate of the power or change required of the near-end transmitter.

To control the transmitter output power of the respective transceiver, each receiver determines the quality of the received signal and provides a local quality signal to its associated transmitter in the respective transceiver indicative of that received signal quality. Each transmitter then transmits the local quality signal provided by the receiver back to the transceiver that transmitted the original transmission. The transceiver is responsive to the local quality signal to control its own transmitter power.

For example, a mobile unit transmits a first signal to a nodal transceiver. The nodal transceiver determines the signal quality of the received

signal by analyzing bit error rate, voice diagnostics, fade or the like to provide the local quality signal. The nodal transceiver then transmits the local quality signal back to the mobile unit which processes the local quality signal along with other factors such as received signal strength, or other measurements will known in the art to determine the output power of mobile unit's transmitter. In a preferred embodiment, the local quality signal is appended to the transmission of a second communication signal. In this manner, two way communication provides a carrier signal upon which the local quality signal is transmitted.

Power adjustment based upon path loss reciprocity alone is subject to several sources of error, including, path non-reciprocity (due to frequency difference), staleness due to transit time delay, and local noise or interference anomalies. Compensation for all these effects is provided in the system and method of the invention by a longer term signal quality monitor, which compares recent past actual error rate statistics, (measured in the forward error correction decoder) and compares against prescribed maximum acceptable error rate statistic. In one embodiment, the signal quality monitor includes a history compiler, situated at either the mobile unit or the nodal transceiver, that records and processes additional factors such as past signal quality measurements, position determination of the mobile unit, past measurements of received signal strength, past determinations of the output power of the received signal and other measurements well known to those in the art to

provide a more comprehensive determination of actual signal quality. The difference is interpreted as a longer-term signal level deficiency.

This signal level deficiency is then telemetered back to the respondent transceiver as an independent short burst transmission or may be appended to the transmission of a second two-way signal, where it is used to provide a longer term supervisory control over the short term path-reciprocity power adjustment system. Thus, for example, if a mobile terminal passes into an urban area where it suffers deep-fast fades that cannot be fully compensated due to the delay in the path reciprocity sensing power control, the longer term signal quality deficiency estimate will sense this and call for a gradual increase in the reference value calibration of the fast, signal sensing power control.

The two derived estimates of the required near-end transmit power or change in power, (near-end signal strength and far-end signal quality), have complementary error characteristics such that an optimal combination of the two estimates will yield an overall estimate far superior to either one separately. The near-end path loss measurement is fast but error prone. The far-end signal quality measurement is slow but accurate. The invention of the adaptive power control system combines these two available measures into a single control system taking advantage of the better features of each. Several approaches to this combination are possible.

present invention includes an adaptive path loss power control system. In an embodiment of the adaptive path loss power control system, each transmitter telemeters its current signal output level to the counterpart far end receiver by adding a low rate data stream to the composite digital output signal. Using this information along with the measured strength of the received signal and assuming path loss reciprocity, each end can form an estimate of the instantaneous path loss and adjust its current transmit power output to a level which will produce an approximately constant received signal level at the counterpart receiver irrespective of path loss variations.

Referring now to FIGS. 8a through 8h, timing and waveform diagrams of the adaptive path loss system of an adaptive power control system in accordance with the principles of the invention are presented. In this example, the two ends of the communications link are referred to generally as A and B. In the ground cellular application, "A" corresponds to the user and "B" corresponds to the cellular node. In the satellite link, A would be the user and B would be the satellite control node; in this case, the satellite is simply a constant gain repeater and the control of its power output is exercised by the level of the signal sent up to it.

In the example of FIG. 8a, at time 192, the path loss suddenly increases x dB due for example to the mobile user A driving behind a building or other obstruction in the immediate vicinity of A. This causes the signal strength as sensed by A's AGC to decrease x dB as shown in FIG. 8b. The telemetered

data at time 192 shown in FIG. 8c indicates that the level at which this signal had been transmitted from B had not been altered, A's power level controller 188 subtracts the telemetered transmitted signal level from the observed received signal level and computes that there has been an increase of x dB in path loss. Accordingly it increases its signal level output by x dB at time 192 as shown in FIG. 8d and at the same time adds this information to its status telemeter channel.

This signal is transmitted to B, arriving after transit time T as shown in FIG. 8e. The B receiver sees a constant received signal strength as shown in FIG. 8f but learns from the telemetered data channel as shown in FIG. 8g that the signal has been sent to him at +x dB. Therefore, B also computes that the path loss has increased x dB, adjusts its output signal level accordingly at FIG. 8h and telemeters that information. That signal increase arrives back at station A at 2T as shown in FIG. 8e thus restoring the nominal signal strength with a delay of two transit times (T). Thus for a path loss variation occurring in the vicinity of A, the path loss compensation at B is seen to be essentially instantaneous while that at A occurs only after a two transit time delay, 2T.

The general hybrid of the adaptive signal quality power control system combined with the adaptive path loss power control system is illustrated in Figure 10. Independent estimates, 250 and 252, of the required power correction are formed based upon the local received signal strength, compensated by telemetered far-end transmit power, and telemetered far-end

signal quality as discussed above. These are filtered in filters 256 and 258 and combined in signal summer 260 to provide the best possible power control 260. Based upon estimates or measurements of the true path loss variability power density spectrum, and the power density spectra of the independent estimates 252 and 254, optimal realizable filters 256 and 258 may be designed by well known Wiener methods and specified in terms of their transfer function or impulsive response characteristics.

Alternatively, and more directly relevant to the preferred embodiments, the independent estimates 252 and 254 and the power control output 262 may be in discrete time sampled digital form. The combiner may then be implemented as a finite state machine computer algorithm (constant coefficient digital filter), designed by well known Kalman-Bucy filter estimation methodology based upon the estimated or measured autocorrelation statistics of the true path loss variation and of the estimate errors of 252 and 254. These statistics are directly related to the power density spectral statistics used to describe the analog implementation of the Fourier transforms of one another.

FIG. 9 also shows the operation of an adaptive signal quality power control system acting in concert with the adaptive path loss power control system described above. While FIG. 9 depicts only one of two corresponding transceivers 210 which are in communication with each other, the one not shown functions identically to the one shown in FIG. 9 and described. Receiver 212 receives the signal from the corresponding transceiver and

provides a measure indicative of the near-end received signal level deviation from a nominal level 214 by techniques well known to those skilled in the art as a step in determining the path loss. The nominal level is typically calculated to provide a desired minimum acceptable grade of service under average conditions of fading and interference, as is well known to those skilled in the art. The receiver 212 provides a digital output signal 213 based on the received signal. Forward error decoder 216 decodes the digital information in the received signal 213, and in the process provides an error rate measure 218, derived from the fraction of transmitted bits needing correction. The forward error decoded signal 218 is further processed in the signal quality circuit 220 to derive signal quality deficiency; i.e., an estimate of the change in transmit power calculated as that which would be required to just achieve the specified, minimum acceptable error rate under average conditions of fading and interference. The output from the signal quality circuit 220 is provided to an analog-to-digital converter 221 to provide a digital signal to be multiplexed 244. If the error rate is higher than acceptable, the signal quality circuit output 222 will include a power increase command signal and if the error rate is less than acceptable, a transmit power reduction will be output.

The circuit of FIG. 9 also includes a consideration of the signal-to-noise ratio (SNR) in the received signal to determine signal quality. The SNR of the received signal is determined in the receiver 212 by techniques well known to those skilled in the art; for example, the AGC is monitored, and an SNR signal 223 is provided to the signal quality circuit 220. In this embodiment, the

signal quality circuit 220 considers both the error rate 218 and the SNR when producing its output control signal 222.

A demultiplexer 224 separates the telemetered data 217 output through the forward error decoder 216 as to far-end signal quality deficiency 226, far-end transmitter power deviation reference 228 from a nominal level, and the traffic signals 230. The far-end transmit power deviation signal 228 is combined 232 with the near-end received signal level deviation 214 to yield a signal 234 representative of the path loss deviation from a nominal reference value. The telemetered far-end signal quality deficiency 226 and the path loss deviation 234 are combined 236 through complementary filters 238 and 240, which may take any of several forms as described above, to yield the transmit power control signal 242 for controlling the output power of the associated transmitter 250. The transmit power control signal 242 is also applied to an analog-to-digital converter 243 to provide a digitized transmit power control signal 245. The resulting transmitter power level deviation from nominal reference 245 and the near-end signal quality 222 deficiency signals are multiplexed 244 with the traffic 246, then forward error encoded 248 and transmitted 250 to the far end transceiver in support of identical functions performed there. In the preferred discrete digitally sampled embodiment, the complementary combining filters 238 and 240 can be designed as optimal estimating filters based upon knowledge of the power requirement signal and measurement error statistics using methods well known to those familiar with estimation theory.

The economic feasibility of a mobile telephone system is related to the number of users that can be supported. Two significant limits on the number of users supported are bandwidth utilization efficiency and power efficiency. In regard to bandwidth utilization efficiency, in either the ground based cellular or mobile satellite elements, radio frequency spectrum allocation is a severely limited commodity. To this end, the power control system of the present invention may be incorporated with other measures to maximize bandwidth utilization efficiency including the use of code division multiple access (CDMA) technology, and spread spectrum communications techniques which provide important spectral utilization efficiency gain and higher spatial frequency reuse, factors made possible by the use of smaller satellite antenna beams.

In regard to power efficiency, which is a major factor for the satellite-mobile links, the power control of the present invention may be combined with the use of forward-error-correcting coding, which in turn is enabled by the above use of spread spectrum code division multiple access (SS/CDMA) technology and by the use of relatively high antenna gain on the satellite. CDMA and forward-error-correction coding are known to those skilled in the art and no further details are given here.

Two-way, adaptive power control and signal quality control system in accordance with the invention provides a flexible capability of providing the following additional special services: high quality, high rate voice and data

service; facsimile (the standard group 3 as well as the high speed group 4); two way messaging, i.e. data interchange between mobile terminals at variable rates; automatic position determination and reporting to within several hundred feet; paging rural residential telephone; and private wireless exchange. Additionally, the system obviates the usual practice of continuously transmitting at a power level which is 10 to 40 dB greater than required most of the time in order to provide a margin for accommodating infrequent deep fades.

It is anticipated that the satellite will utilize geostationary orbits but is not restricted to such. The invention permits operating in other orbits as well. While a satellite node has been described above, it is not intended that this be the only means of providing above-ground service. In the case where a satellite has failed or is unable to provide the desired level of service for other reasons, for example, the satellite has been jammed by a hostile entity, an aircraft or other super-surface vehicle may be commissioned to provide the satellite functions described above. The "surface" nodes described above may be located on the ground or in water bodies on the surface of the earth. Additionally, while users have been shown and described as being located in automobiles, other users may exist. For example, a satellite may be a user of the system for communicating signals, just as a ship at sea may or a user on foot.

While several particular forms of the invention have been illustrated and described, it will be apparent that various modifications can be made without departing from the spirit and scope of the invention. Accordingly, it is not intended that the invention be limited, except by the appended claims.

Having described the invention in such terms as to enable those skilled in the art to make and use it and having identified the presently known and preferred best modes thereof, I claim:

1. A cellular communication power control system comprising:

a first transceiver comprising

a first receiver for receiving a first signal,

a quality measurement means for determining the quality of said first signal and for generating a first quality signal representative of the quality of said first signal, and

a first transmitter for transmitting a second signal and said first quality signal;

a second transceiver comprising

a second transmitter for transmitting said first signal,

a second receiver for receiving said second signal and said first quality signal,

a signal strength measurement means for measuring the signal strength of said second signal,

a processor means for processing said first quality signal, compiled history data relating to the cellular communication system and said signal strength of said second signal for providing a first path loss signal;

a controller means for controlling the output power level of said first signal in accordance with said first path loss signal; and

a history compilation means for continuously compiling history data relating to the cellular communication system.

2. A cellular communication system as in claim 1 wherein:

said second transceiver further comprises:

a quality means for determining the quality of said second signal and for producing a second quality signal representative of the quality of said second signal, and

said second transmitter for transmitting said first signal and said second quality signal;

said first transceiver further comprises:

said first receiver for receiving said first signal and said second quality signal,

a signal strength measurement means for measuring the signal strength of said first signal,

a processor means for processing said second quality signal, said compiled history data and said signal strength of said first signal for providing a second path loss signal, and

a controller means for controlling the output power level of said second signal in accordance with said second path loss signal.

3. A cellular communication system as in claim 1 wherein:

said first transceiver further comprises:

a first level indicator means which generates a first level signal indicative of the output power level of said first transmitter, and

said first transmitter transmits said second signal at a controllable power level and said first level signal;

said second transceiver further comprises:

said processor means further processes said first level signal for comparing said transmitted first level signal to the locally received signal strength of said second signal to provide said first path loss signal.

4. A cellular communication system as in claim 2 wherein:

said first transceiver further comprises:

a first level indicator means which generates a first level signal indicative of the output power level of said first transmitter,

said first transmitter transmits said second signal at a controllable power level and said first level signal, and

said processor means further processes a second level signal for comparing said second level signal to the locally received signal strength of said first signal to provide said second path loss signal;

said second transceiver further comprises:

a second level indicator means which generates said second level signal indicative of the output power level of said second transmitter,

said second transmitter transmits said first signal at a controllable power level and said second level signal, and

said processor means further processes said first level signal for comparing said transmitted first level signal to the locally received signal strength of said second signal to provide said first path loss signal.

5. A method for communicating between first and second transceivers, each transceiver comprising a transmitter and a receiver, the method comprising:

generating a quality signal representative of the quality of a received first signal;

transmitting the quality signal of the respective transceiver and a second signal to the other transceiver;

compiling history data relating to the communication system;

receiving the transmitted quality signal and second signal from the other transceiver;

measuring the signal strength of the received second signal;

processing the quality signal and the signal strength of the second signal to provide a path loss signal; and

controlling the associated transmitter output power level in response to the path loss signal.

6. A cellular communication power control system comprising:

a first transceiver comprising

a first receiver for receiving a first signal,

a quality measurement means for determining the quality of said first signal and for generating a first quality signal representative of the quality of said first signal, and

a first transmitter for transmitting a second signal being different and distinct from said first signal and including said first quality signal;

a second transceiver comprising

a second transmitter for transmitting said first signal,

a second receiver for receiving said second signal and said first quality signal,

a signal strength measurement means for measuring the signal strength of said second signal,

a processor means for processing said first quality signal and said signal strength of said second signal for providing a path loss signal, and

controller means for controlling the output power level of said first signal in accordance with said path loss signal.

7. A cellular communication system as in claim 6 wherein:

said second transceiver further comprises:

a quality means for determining the quality of said second signal and for producing a second quality signal representative of the quality of said second signal, and

said second transmitter for transmitting said first signal being different and distinct from said second signal and including said second quality signal;

said first transceiver further comprises:

said first receiver for receiving said first signal and said second quality signal,

a signal strength measurement means for measuring the signal strength of said first signal,

a processor means for processing said second quality signal and said signal strength of said first signal for providing a path loss signal, and

a controller means for controlling the output power level of said second signal in accordance with said path loss signal.

8. A cellular communication system as in claim 6 wherein:

said first transceiver further comprises:

a first level indicator means which generates a first level signal indicative of the output power level of said first transmitter, and

said first transmitter transmits said second signal at a controllable power level and said first level signal;

said second transceiver further comprises:

said processor means further processes said first level signal for comparing said transmitted first level signal to the locally received signal strength of said second signal to provide said first path loss signal.

9. A cellular communication system as in claim 7 wherein:

said first transceiver further comprises:

a first level indicator means which generates a first level signal indicative of the output power level of said first transmitter,

said first transmitter transmits said second signal at a controllable power level and said first level signal, and

said processor means further processes a second level signal for comparing said second level signal to the locally received signal strength of said first signal to provide said second path loss signal;

said second transceiver further comprises:

a second level indicator means which generates said second level signal indicative of the output power level of said second transmitter,

said second transmitter transmits said first signal at a controllable power level and said second level signal, and

said processor means further processes said first level signal for comparing said transmitted first level signal to the locally received signal strength of said second signal to provide said first path loss signal.

10. A method for communicating between first and second transceivers, each transceiver comprising a transmitter and a receiver, the method comprising:

generating a quality signal representative of the quality of a received first signal;

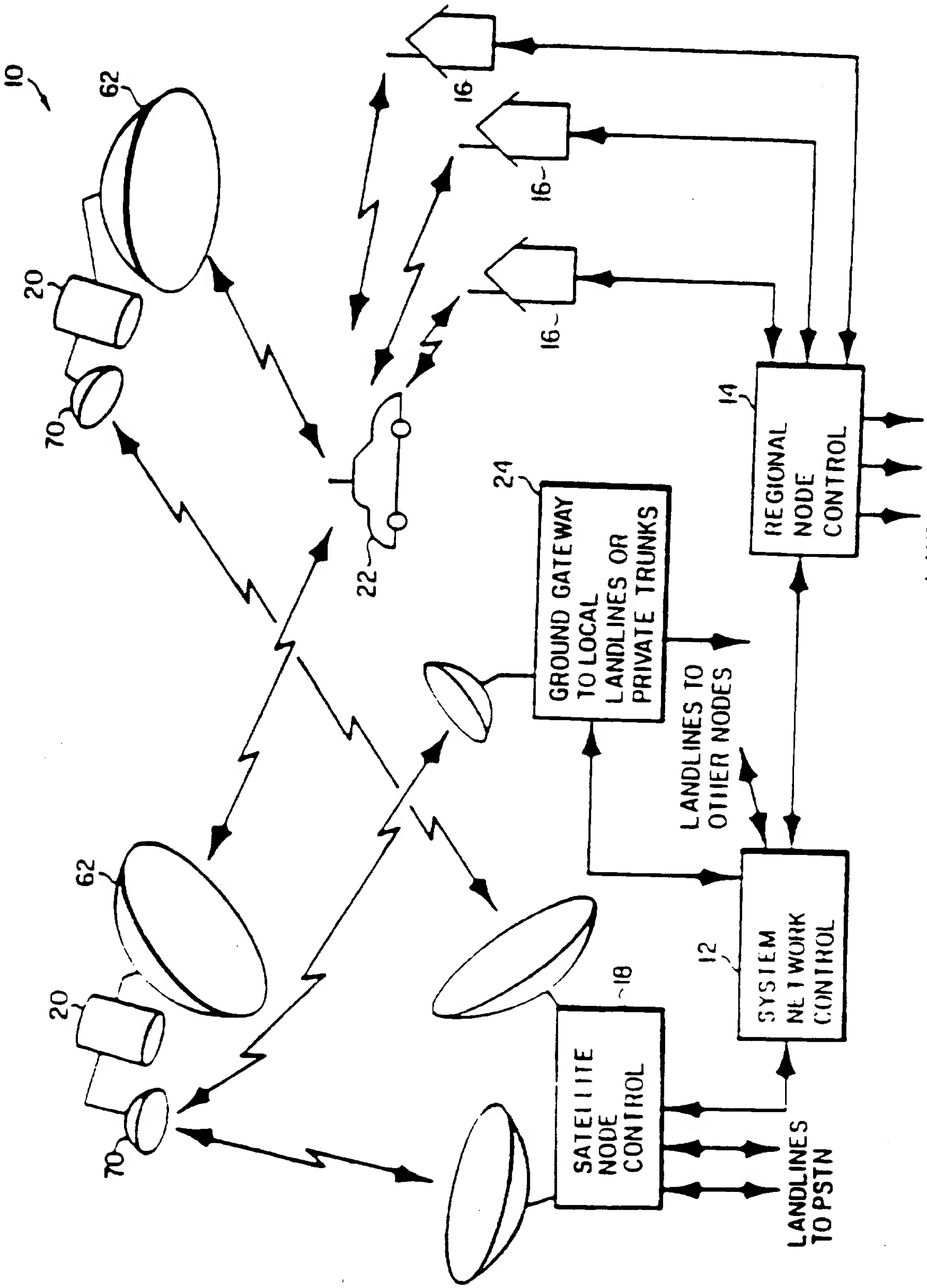
transmitting a second signal being different and distinct from said first signal and including the second quality signal to the other transceiver;

receiving the transmitted quality signal and second signal from the other transceiver;

measuring the signal strength of the received second signal;

processing the quality signal and the signal strength of the second signal to provide a path loss signal; and

controlling the associated transmitter output power level in response to the path loss signal.


10
62
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16
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16
22
24
GROUND GATEWAY TO LOCAL LANDLINES OR PRIVATE TRUNKS
LANDLINES TO OTHER NODES
14
REGIONAL NODE CONTROL
LANDLINES TO PSTN
62
20
70
18
SATELLITE NODE CONTROL
LANDLINES TO PSTN
12
SYSTEM NETWORK CONTROL

FIG.1

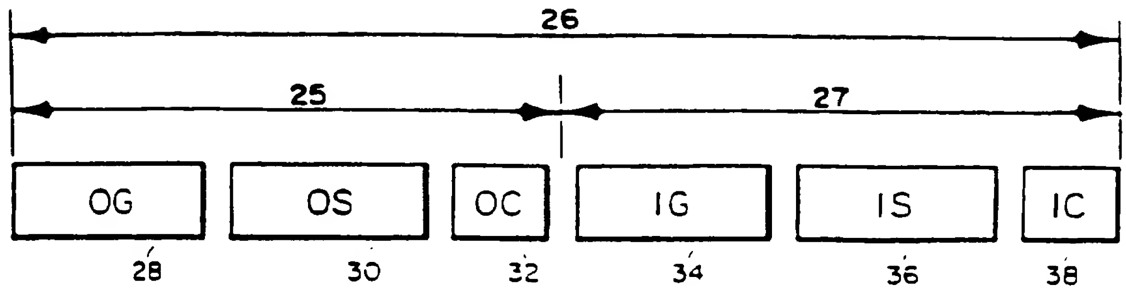


FIG 2

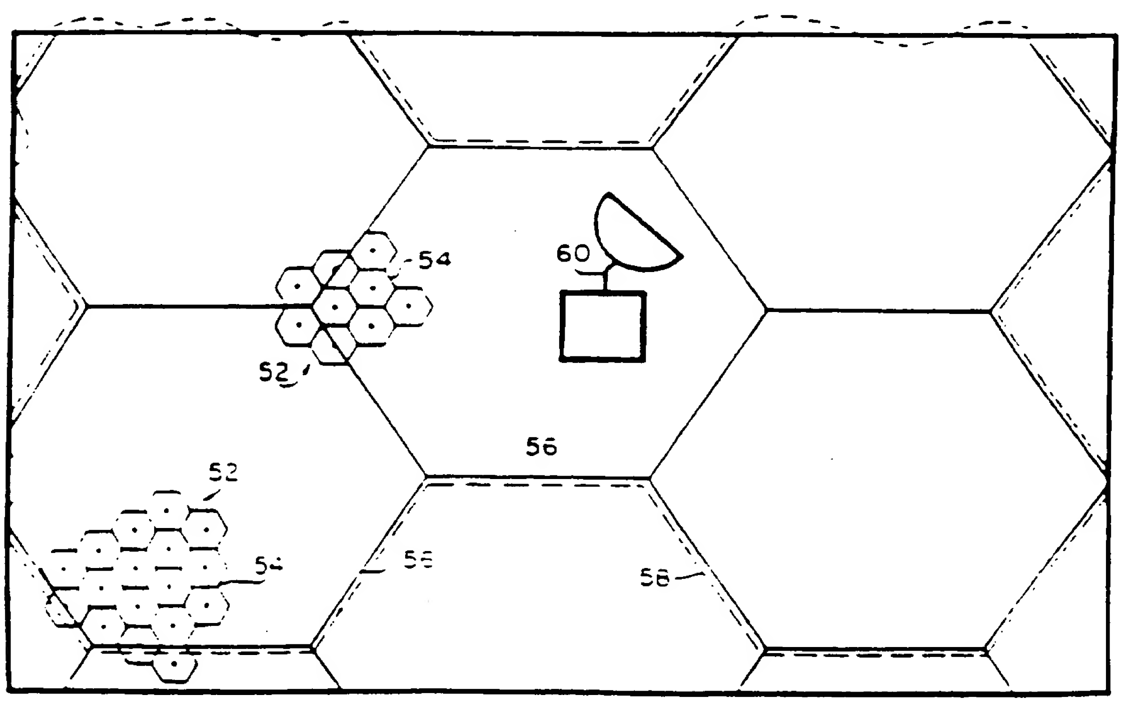
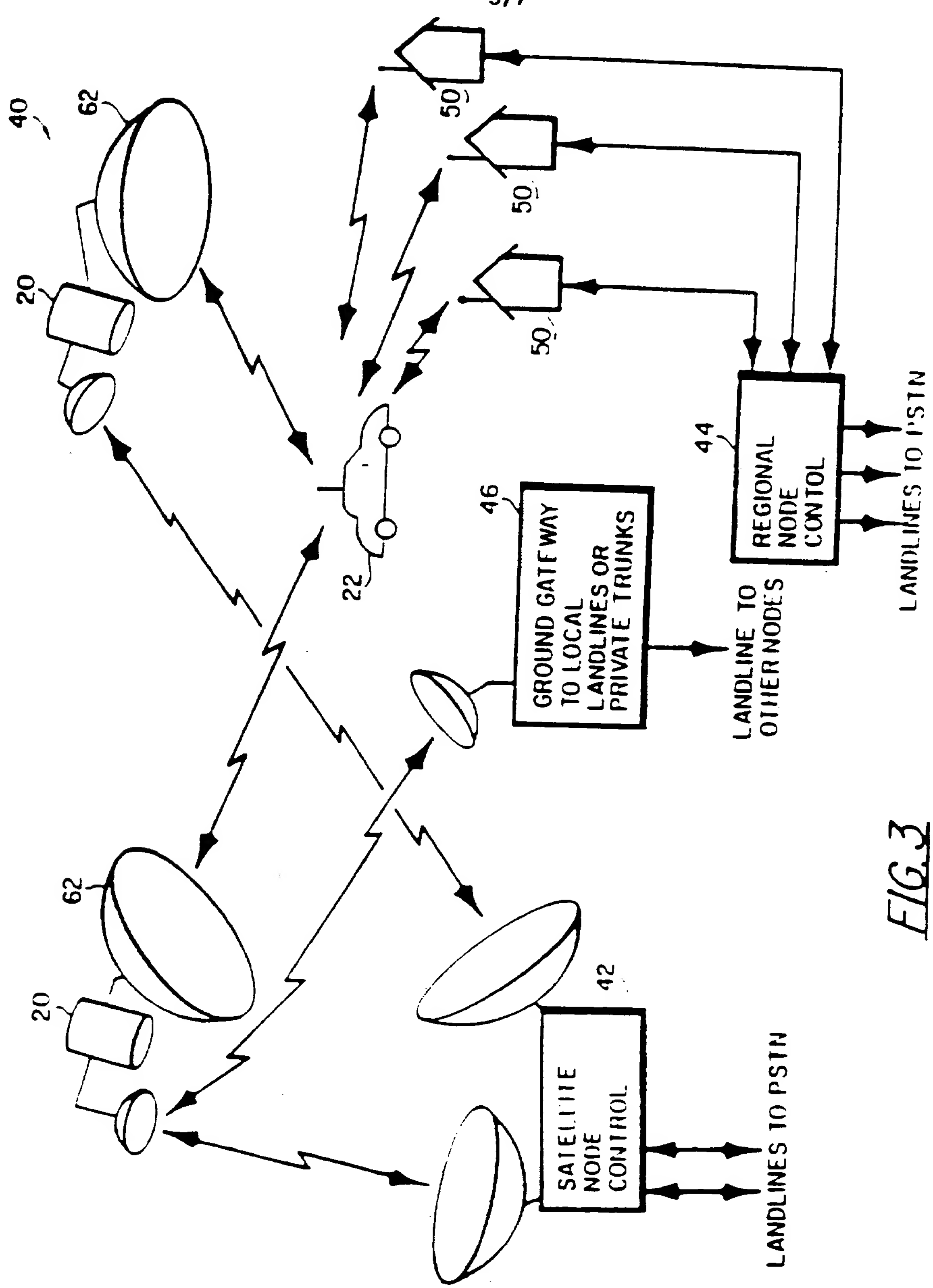


FIG 4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62
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50
22
46
GROUND GATEWAY TO LOCAL LANDLINES OR PRIVATE TRUNKS
44
REGIONAL NODE CONTOL
LANDLINE TO OTHER NODES
LANDLINES TO PSTN
62
20
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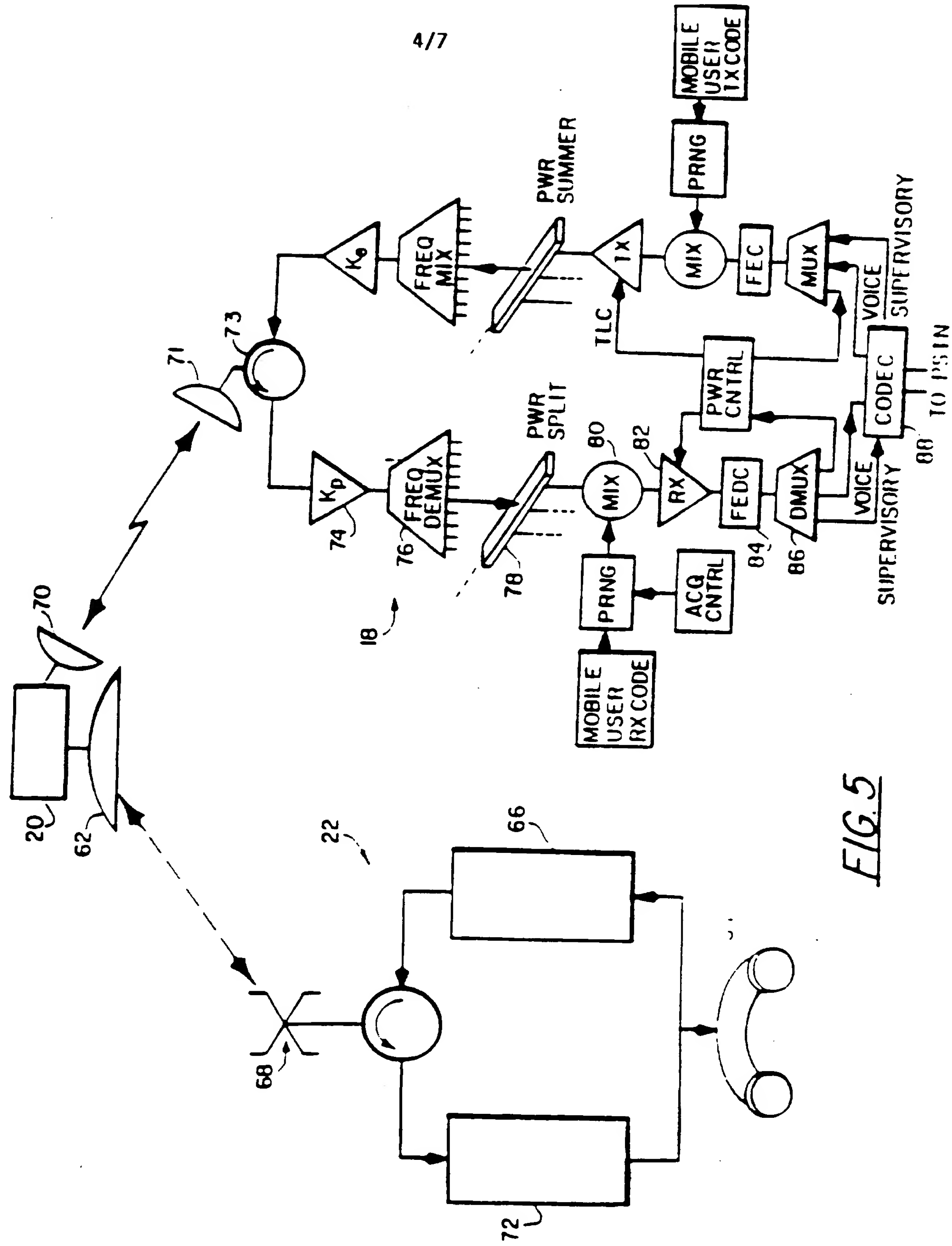
SATELLITE NODE CONTROL
LANDLINES TO PSTN

FIG. 3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PRNG
PWR SUMMER
FREQ MIX
TX
MIX
FEC
MUX
VOICE
SUPERVISORY
TLC
PWR CNTRL
CODEC
TO PSTN
PWR SPLIT
FREQ DEMUX
MIX
RX
FEDC
DMUX
VOICE
SUPERVISORY
PRNG
ACQ CNTRL
MOBILE USER RX CODE
20
62
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71
73
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78
80
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84
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88
18
22
66
68
72

FIG. 5

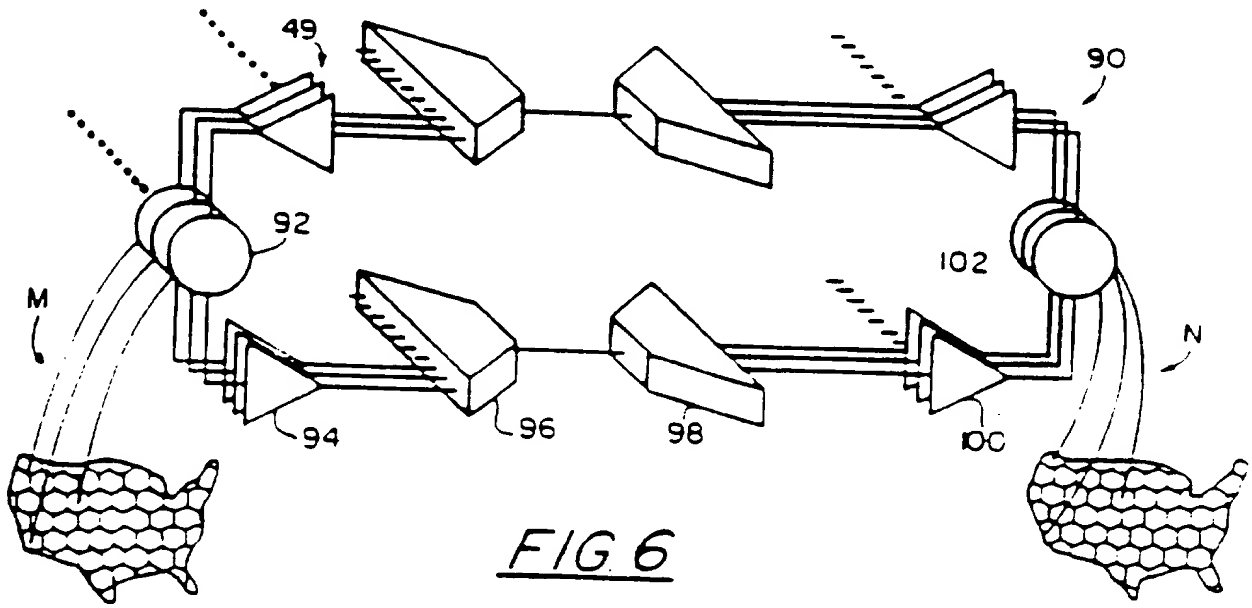
49
90
92
102
M
N
94
96
98
100

FIG 6

192

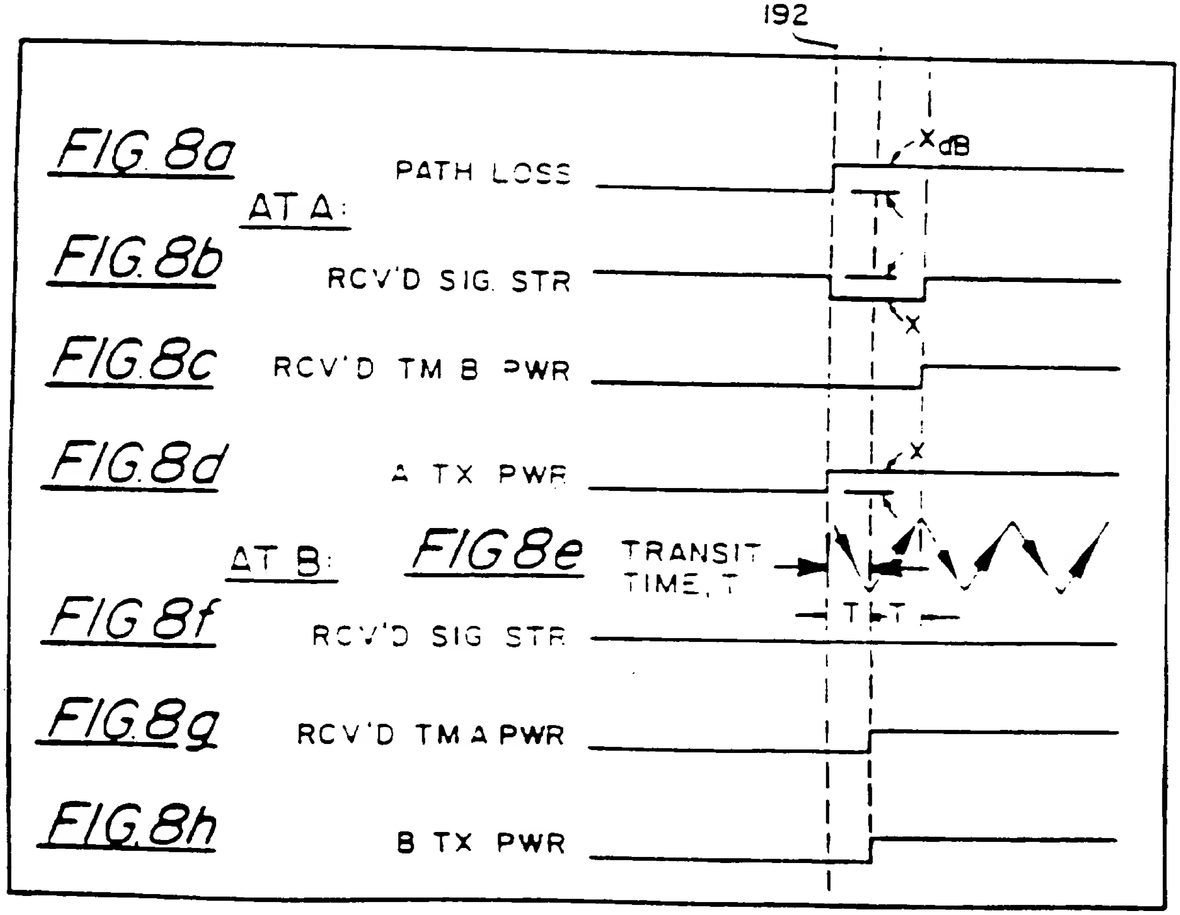
FIG 8a
PATH LOSS
X dB
AT A:
FIG 8b
RCV'D SIG STR
X
FIG 8c
RCV'D TM B PWR
FIG 8d
A TX PWR
X
AT B:
FIG 8e
TRANSIT
TIME, T
T
T
FIG 8f
RCV'D SIG STR
FIG 8g
RCV'D TM A PWR
FIG 8h
B TX PWR

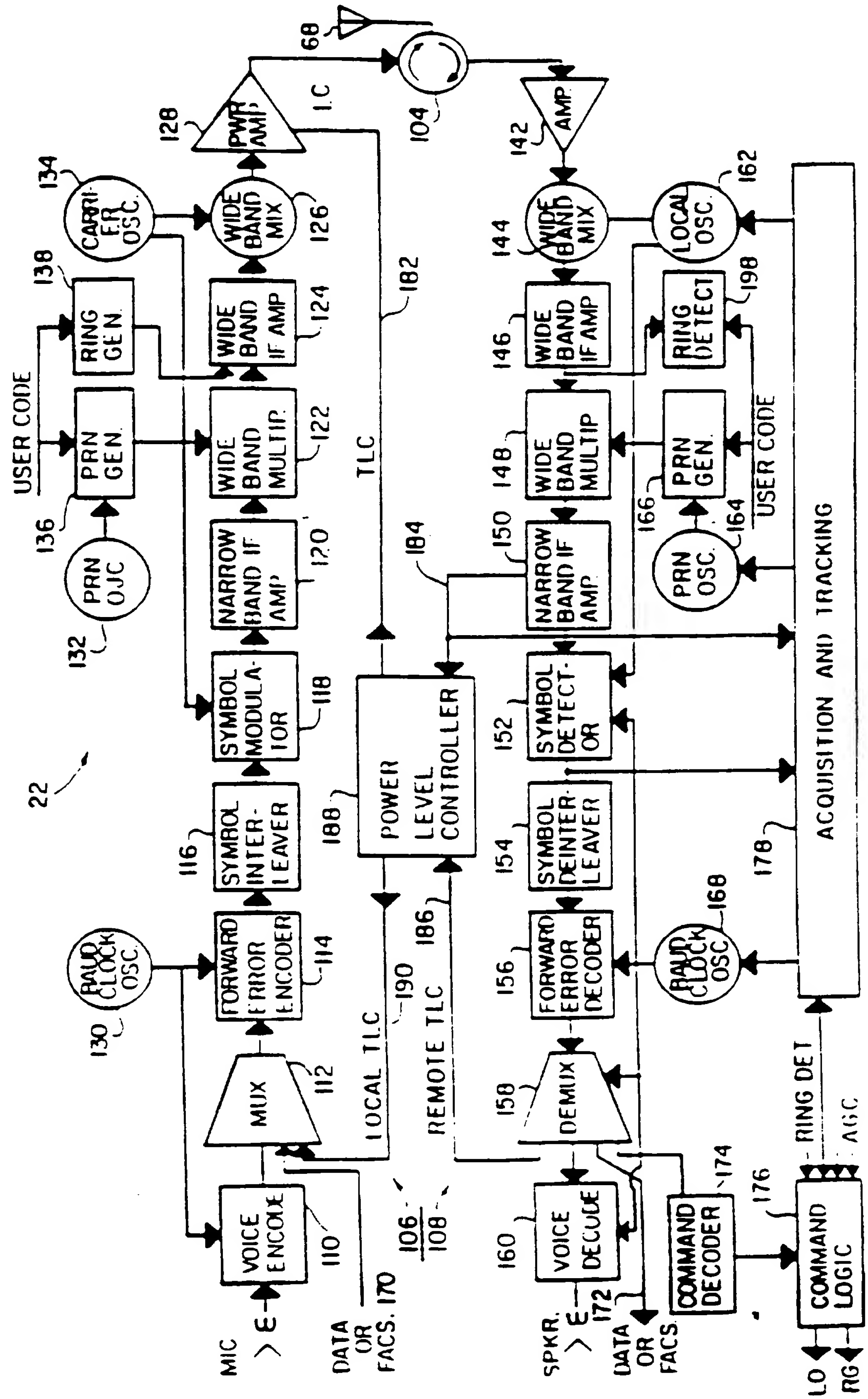

FIG.7

SUBSTITUTE SHEET (RULE 26)

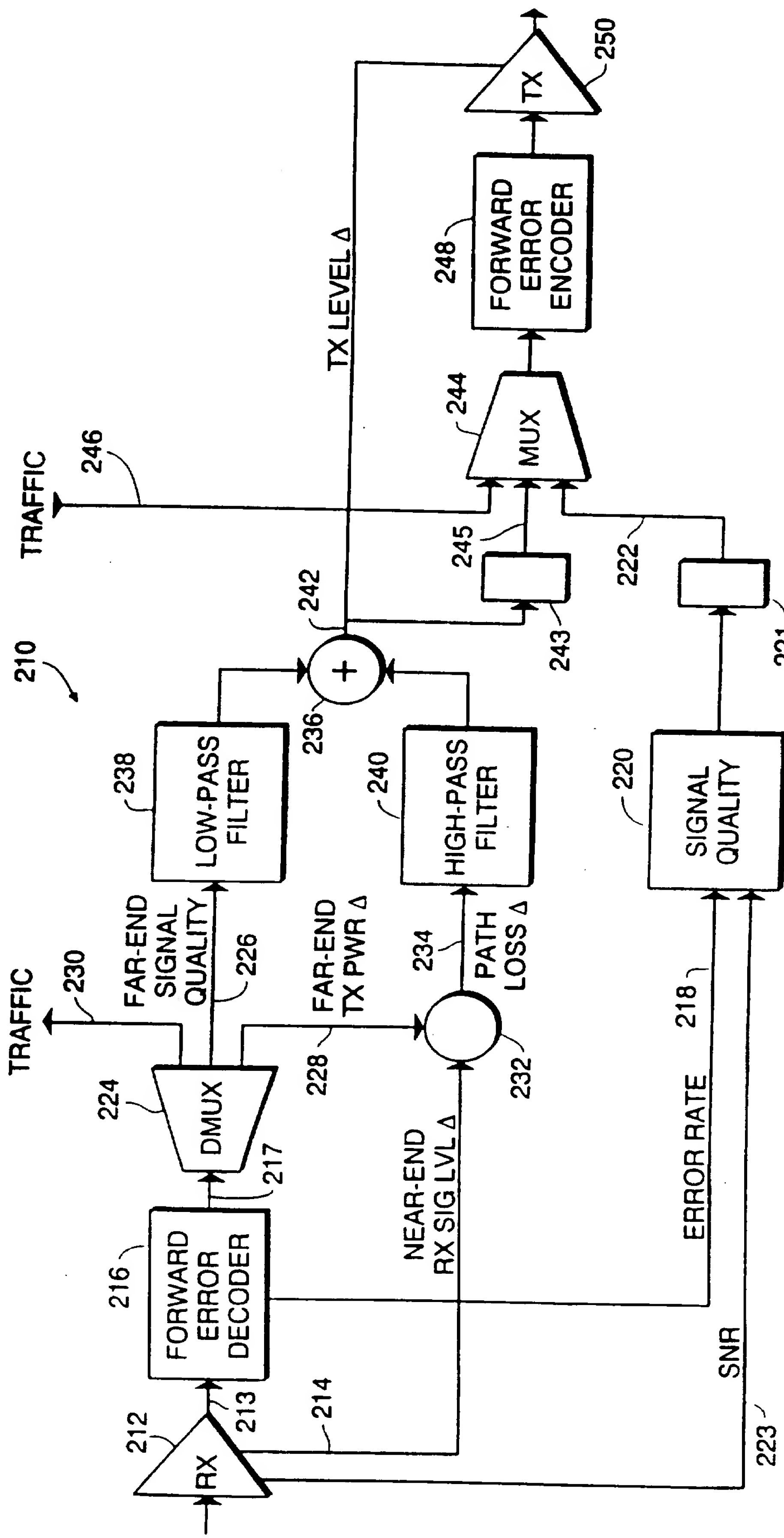
210
RX
212
213
214
FORWARD ERROR DECODER
216
217
DMUX
224
TRAFFIC
230
FAR-END SIGNAL QUALITY
226
FAR-END TX PWR Δ
228
NEAR-END RX SIG LVL Δ
232
PATH LOSS Δ
234
LOW-PASS FILTER
238
HIGH-PASS FILTER
240
236
242
TX LEVEL Δ
243
245
TRAFFIC
246
MUX
244
FORWARD ERROR ENCODER
248
TX
250
ERROR RATE
218
SNR
223
SIGNAL QUALITY
220
221
222

FIG. 9

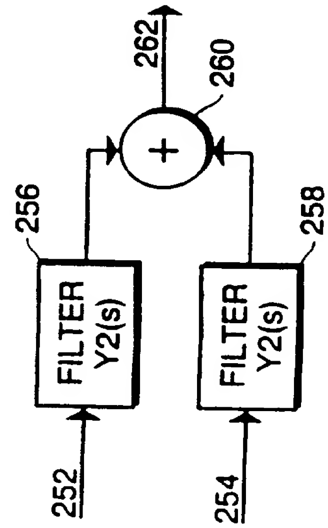
FILTER Y2(s)
256
252
FILTER Y2(s)
258
254
260
262

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/03898

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :HO4B 1/034, 7/26; H04M 11/00
US CL :455/38.3
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/33.1, 38.3, 52.1, 54.1, 63, 65, 67.1, 69, 88, 89, 115, 126, 127; 379/58,59

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,333,175 (Ariyavisitakul et al.) 26 July 1994 see FIGS. 2 and 3	1-10
A	US, A, 4,777,653 (Bonnerot et al.) 11 October 1988 see FIG. 1	1-10
A	US, A, 5,265,119 (Gilhousen et al.) 23 November 1993 see FIGS. 3 and 4	1-10
A	US, A, 5,386, 589 (Kanai) 31 January 1995 see FIG.3	1-10
A	US, A, 5,241,690 (Larsson et al.) 31 August 1993 see FIG. 4	1-10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 MAY 1995	16 AUG 1995

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	B. Harold MARSHA D. BANKS-HAROLD for
Facsimile No. (703) 305-3230	Telephone No. (703) 305-4379